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RF and IF Digitization in Radio Receivers: Theory, Concepts, and Examples

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RF AND IF DIGITIZATION IN RADIO RECEIVERS: THEORY, CONCEPTS, AND EXAMPLES

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Hardware development of analog-to-digital converters (ADC's) and digital signal processors, including specialized integrated circuits, has advanced rapidly within the last few years. These advances have paved the way for development of radio receivers using digitization at the IF and in some cases at the RF. Applications for these receivers are expected to increase rapidly in areas such as cellular mobile, satellite, and personal communications services (PCS) systems. The constraints placed on these receivers due to hardware limitations of these devices are investigated in this paper. Some examples of state-of-the-art ADC's, signal processors, and specialized integrated circuits are listed. Various quantization techniques, nonlinear compression devices, postdigitization algorithms for improving dynamic range, sampling downconverters, and specialized integrated circuits are discussed as they are expected to be useful in the development of these types of receivers. Several examples of radio receivers employing digitization at the IF and RF are also presented.

Key words: analog-to-digital converters; automatic gain control devices; digital signal processors; digitization; logarithmic amplifiers; quantization; radio receivers; sampling downconverters; signal-to-noise ratio; spurious free dynamic range

1. INTRODUCTION

As advances in technology provide increasingly faster and less expensive digital hardware, more of the traditionally analog functions of a radio receiver will be replaced with software or digital hardware. The final goal for radio receiver design is to directly digitize the RF signal at the output of the receive antenna and therefore implement all receiver functions in either digital hardware or software. The trend in receiver design is evolving toward this goal by incorporating digitization closer and closer to the receive antenna for systems at increasingly higher frequencies and wider bandwidths. Analog RF front-ends with digitization at either baseband or IF are currently being implemented in many arenas.

There is keen interest in replacing analog hardware with digital signal processing in radio receivers for several reasons. One reason is the potential for the reduction in product development time since changes can be implemented in software instead of altering the hardware [1]. Digital technology can offer a more ideal performance for implementing signal-processing functions. The repeatability and temperature stability can be substantially better.

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Functions that are not implementable in analog hardware can be implemented in software. An example is the design of finite impulse response (FIR) filters that simultaneously can achieve sharp rolloff and linear phase. Another advantage is that digitally implemented signal-processing functions do not require the tuning or "tweaking" typically required in an analog implementation to achieve the desired performance [2]. (Proper operation of digital processing circuitry does require some level of synchronization, however.) Cost-effective multipurpose radios can be designed to allow reception of different modulation types and bandwidths simply by changing the software that controls the radio. The final benefit is the cost savings in implementing the receiver.

As radio receiver design evolves so that direct digitization of the RF input signal becomes more commonplace, these systems will have to go through the process of spectrum certification before they can be implemented and used by Government agencies. The process of spectrum certification includes an electromagnetic compatibility (EMC) analysis. Development of EMC analysis methodologies and a spectrum certification process for radio receivers using digitization at the RF is required to help the National Telecommunications and Information Administration (NTIA) manage the Federal radio spectrum for Government agencies in the most efficient manner possible.

Methods for analyzing EMC in traditional receivers (such as the superheterodyne) are well established. EMC analysis of these new receivers that utilize digitization of the RF signal at the front-end may be different. Information currently requested by NTIA for receiver equipment characteristics that is used in the EMC analyses may no longer be relevant for these new types of receivers. Detailed knowledge of how these receivers operate is therefore required to help develop appropriate methods of EMC analysis. This report provides more information on these types of radio receivers. In Section 2, we discuss analog-to-digital converters (ADC's), one of the important components needed in radio receivers using digitization at the RF or IF. The requirements, practical limitations, and potential problems for ADC's are presented. Section 3 includes the signal-processing requirements and limitations for radio receivers that digitize at the RF or IF. Some devices and techniques that may be useful for receivers employing direct digitization of the RF are described in Section 4. These include 1) methods of nonuniform quantization, 2) nonlinear amplitude compression devices, 3) algorithms for improving dynamic range, 4) sampling downconverters, and 5) specialized integrated circuits. Chapter 5 presents some examples of radios that digitize at the RF or IF. Chapter 6 provides a brief summary of this investigation and some recommendations for further work in this area.